AEEM HVAC ENERGY VALVE

Prototype Build Guide

Measurement-first HVAC energy intelligence prototype for disconnect-adjacent installation. V0 proves sensing and adaptive learning before any experimental hardware is allowed to supervise HVAC operation.

Version	Purpose	Rule
V0	Measure and learn	No experimental compressor power switching
V1	Supervisory HVAC control	Use isolated low-voltage HVAC control interface
V2	Integrated product concept	Add engineered/certified SPD stage and product enclosure

1. V0 Architecture

Install the prototype enclosure beside the existing outdoor disconnect. Keep the existing disconnect fully functional and accessible. Use split-core current transformers for non-invasive current sensing. Any line-voltage metering should use appropriately isolated, rated hardware and qualified installation practices.

```
240-V PANEL | v EXISTING HVAC DISCONNECT | +-- CT on L1 +-- CT on L2 | v CONDENSER / HEAT PUMP AEEM ENCLOSURE BESIDE DISCONNECT +-- ESP32 controller +-- CT interfaces +-- isolated power meter +-- temperature sensors +-- thermostat-call sensing +-- local logging / Wi-Fi
```

2. Prototype BOM

Part	Function	Rough cost
ESP32-S3 development board	Main controller / Wi-Fi	$10-$20
2 split-core CTs	L1/L2 current sensing	$20-$50
Isolated true-power / energy meter	Voltage, watts, PF, kWh	$25-$80
4-6 temperature probes	Line / ambient / air temperatures	$15-$35
Temperature + RH sensor	Indoor environmental normalization	$5-$15
24-VAC isolated inputs	Y/G/W/O-B call detection	$15-$40
MicroSD module	Raw data logging	$5-$10
Isolated low-voltage supply	Controller power	$15-$30
Outdoor enclosure + DIN rail + glands	Mechanical integration	$35-$100

Expected V0 prototype cost: approximately $145-$380 before labor, certification work, and optional commercial SPD reference hardware.

3. Sensor Placement

Location	Measurement	Why
Outdoor unit	L1/L2 current + real power	Starts, runtime, kWh, abnormal load
Outdoor unit	Outdoor air temperature	Weather normalization
Refrigerant lines	Suction + liquid line temperature	Trend equipment behavior
Indoor return	Return-air temperature + RH	Starting condition / latent load
Indoor supply	Supply-air temperature	Thermal response
Thermostat/control wiring	Y/G/W/O-B call state	Tie electrical behavior to commands
Optional indoor blower	Blower current	Air-handler operating state

4. Firmware Logging Schema

Log raw data every 5-10 seconds. Do not discard the original measurements.

```
timestamp voltage L1_current L2_current real_watts power_factor total_kWh outdoor_temp indoor_temp
indoor_RH supply_temp return_temp suction_line_temp liquid_line_temp Y_call G_call W_call OB_call
compressor_state cycle_number cycle_runtime
```

5. Operating-State Detection

Begin with conservative threshold-based state classification. Replace rigid thresholds with learned equipment fingerprints only after enough clean data exists.

State	Initial signature
OFF	Near-zero HVAC branch load
FAN_ONLY	Indoor blower detected without compressor
COMPRESSOR_START	Short-duration high-current event
COOLING_STEADY	Stable compressor/fan power + cooling call
HEATING_STEADY	Heat-pump or heat call signature
DEFROST	Heat-pump signature change + O/B/control context
AUX_HEAT	High resistance-heat load or W/AUX call
ABNORMAL	Pattern outside learned tolerance

6. Primary Learned Metric

Use an Energy Performance Index (EPI): useful thermal response divided by electrical energy consumed, normalized for outdoor temperature, humidity, indoor starting condition and equipment state. This is a repeatable relative metric for the same HVAC system, not a laboratory COP/SEER measurement.

Example: if comparable hot-weather conditions historically require 1.8 kWh for a defined cooling response and later require 2.2 kWh, the system is using about 22% more energy for the same measured result. That should trigger a health investigation.

7. Adaptive Learning Timeline

Time	Learning phase	Expected output
Days 1-3	Fingerprint	Starts, steady watts, cycle lengths, basic thermal response
Days 4-7	Environmental normalization	Weather / humidity / starting-condition corrections
Days 7-14	Useful model	Health score, excessive cycling, abnormal runtime alerts
Days 14-30	Active optimization-ready	Recovery prediction and household-specific strategy
Days 30-60	Stable personalized model	Most recurring adaptive effects visible
90+ days	Seasonal refinement	Stronger seasonal and weather baselines

8. V1 Low-Voltage Control Bridge

```
THERMOSTAT | v AEEM ISOLATED CONTROL BRIDGE | +-- R / C +-- Y +-- G +-- W / AUX +-- O/B | v HVAC EQUIPMENT
```

Normal optimization should supervise the HVAC low-voltage control path rather than repeatedly opening the 240-V compressor feed. Hard limits should include minimum compressor off-time, minimum run-time, maximum cycles per hour, thermostat override, fault bypass and fail-safe behavior.

Adaptive functions can then include:

• Recovery-time prediction

• Pre-cooling / pre-heating

• Humidity-aware operation

• Tariff-aware operation

• Peak-demand avoidance

• Reduced unnecessary auxiliary resistance heat where the equipment allows it

9. A/B Validation Mode

Mode A - Observe only. AEEM records behavior but does not alter operation.
Mode B - Optimize. AEEM supervises HVAC calls using the learned strategy.

Alternate the modes under comparable weather and occupancy. The prototype passes only if Mode B maintains comparable indoor comfort and humidity while using less normalized HVAC energy.

10. V2 Surge-Protection Integration

The production product can legitimately double as surge protection only when a dedicated surge-protective stage is intentionally engineered and separately validated. Monitoring/control electronics alone do not make the device an SPD.

```
PANEL | v AEEM HVAC ENERGY VALVE +-- surge-protection stage +-- energy metering +-- controller / health model +-- isolated HVAC I/O | v EXISTING HVAC DISCONNECT | v HVAC UNIT
```

For prototype work, use a commercially rated HVAC SPD as the reference protection module rather than building an untested mains surge-clamping network. If the commercial SPD provides a status/alarm output, log that state in AEEM so the final product can report protective-element health.

11. Recommended Prototype Enclosure

```
8 x 6 x 4 in class outdoor enclosure LOW-VOLTAGE SECTION ESP32 SD storage sensor interfaces isolated HVAC I/O ------------------------ PHYSICAL ISOLATION BARRIER ------------------------ RATED INTERFACE SECTION CT terminals isolated power meter commercial SPD status interface
```

Keep line-associated wiring and low-voltage logic physically segregated. Use outdoor-rated glands, terminals, enclosure, strain relief, and appropriately rated conductors/components.

12. Prototype Success Targets

Test	Initial pass target
Energy measurement	Within about 2% of a reference meter
Compressor-state detection	>99%
Cycle detection	>99%
Temperature repeatability	About +/-0.5 F desirable
Data uptime	>99%
False fault warnings	<1 per week initially
Useful learning period	<=14 days
Stable personalized model	<=60 days
Normalized adaptive savings	>=5% HVAC kWh
Stretch savings target	8-12% in suitable homes
Comfort degradation	Negligible / user-defined limits maintained

13. First Physical Build

Build this first: ESP32 + two CTs + isolated energy meter + six temperature channels + humidity + thermostat-call sensing + SD logging + commercial HVAC SPD status monitoring.

Do not add compressor-power switching to the first build. Run V0 on one HVAC system long enough to establish whether the model can predict expected energy consumption under comparable operating conditions. Once that model is reliable, add the isolated V1 thermostat supervisory bridge.

Go / No-Go sequence

1. Verify measurement accuracy against a known reference.

2. Verify automatic cycle/state detection.

3. Build a weather-normalized baseline.

4. Demonstrate repeatable degradation/anomaly detection.

5. Add V1 control and run A/B validation.

6. Require >=5% normalized savings before production architecture work.

7. Pursue final SPD design, listing/certification and integrated enclosure only after control value is proven.

Safety boundary: this guide intentionally keeps experimental logic out of the normal 240-V compressor switching path. Any line-voltage connection, branch-circuit alteration, surge-protection installation or final field installation should use appropriately rated/listed equipment and qualified electrical/HVAC practices.

Design basis

• NFPA 70 / NEC HVAC disconnect requirements for field installation.

• ENERGY STAR smart thermostat field-performance approach for measured HVAC savings.

• UL 1449 framework for surge protective devices in the future integrated product.

• DOE residential HVAC controls and diagnostics research as the broader technical context.